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Energy Storage

Energy storage will play an important role in meeting North Carolina Session Law 2021-165 ("HB 951") CO_2 emissions reductions targets. In fact, all portfolios presented in Chapter 3 (Portfolios) require the addition of significant storage assets in the Carolinas to achieve the 70% interim emissions reductions target. This additional energy storage capacity will support the continued and increasing pace of connecting carbon-free intermittent resources, e.g., solar and wind, to the grid. As the adoption of these resources continues to increase, the need for, and value of, additional storage will continue to grow. Additionally, Duke Energy Carolinas, LLC's ("DEC") and Duke Energy Progress, LLC's ("DEP" and, together with DEC, "Duke Energy" or the "Companies") portfolio analysis, as discussed in Chapter 3 (Portfolios) shows that energy storage is cost-competitive with peaking generation over the planning horizon. Note that while energy storage of all forms will be of value to the Companies in this energy system transformation, this Appendix focuses on front-of-the-meter storage that supports the bulk power system and grid applications. While "grid-edge" or customer-connected, behind-the-meter storage solutions are no less important to decarbonizing the grid in the Carolinas, these customer programs are discussed in Appendix G (Grid Edge and Customer Programs).

Long-duration storage is an essential part of the Companies' decarbonization portfolios. As the penetration of renewables increases and the Companies retire baseload generation from coal and gas, there will be an increased need for low-carbon firm capacity. Supply and demand must be balanced in real time to maintain adequate frequency and voltage on the grid, meaning that there must be enough firm capacity during the highest peak hour of the year. With the increase of intermittent generation, energy storage, particularly long-duration energy storage, will become increasingly important to maintaining grid reliability.

Today, energy storage systems primarily provide regulation and reserve ancillary services. These services become especially important as renewable integration increases and they can be provided using relatively short-duration energy storage systems. However, as the total installed capacity of energy storage systems increases, these systems will increasingly provide capacity and decarbonization services. Those services require longer-duration storage. With the growing market for long-duration storage, the development of new storage technologies that have more flexible siting than pumped storage hydro ("PSH") and are cost competitive to existing lithium-ion technologies at extended durations are essential to making the clean energy transition affordable.

Current Status of Energy Storage in the Carolinas

For over a decade, the Companies have been piloting emerging battery storage technologies at several sites in the Carolinas. For example, the McAlpine Substation Energy Storage and Microgrid Project in Charlotte, N.C. was commissioned in late 2012. At the state-of-the-art research center in Mount Holly, N.C., the Companies continue to collaborate with vendors, utilities, research labs and government agencies to develop and commercialize an interoperability framework that enables the integration of distributed resources and demonstrates alternative approaches for microgrid operations.

In addition to battery storage, long-duration storage is currently realized on the system in the form of PSH totaling 2,300 megawatts ("MW") of capacity between Jocassee and Bad Creek pumped storage hydro systems. A summary of all energy storage currently installed on the Companies' system in the Carolinas is presented in Table K-1 below.

Table K-1: Energy Storage Systems Located in the Carolinas

System	Location	Type of System	Service Date	Size
Jocassee	Pickens/Oconee County, SC	Pumped Storage Hydro	1973	780 MW
Bad Creek	Oconee County, SC	Pumped Storage Hydro	1991	1,520 MW
Mt. Sterling Microgrid	Haywood County, NC	Battery Storage	2017	95 kWh
AVL Rock Hill	Buncombe County, NC	Battery Storage	2020	9 MW
Hot Springs Microgrid	Madison County, NC	Battery Storage	2021	4 MW

Bad Creek I Uprates

The Companies will increase the capacity of the original Bad Creek facility by approximately 280 MW by 2024 through facility upgrades. The planned uprates include installing four more efficient and powerful pump turbines, three higher-rated generator step-up transformers, new generators, and new higher-rated generator output circuit breakers. The additional output from the Bad Creek facility resulting from these upgrades is assumed in the Carbon Plan modeling, as discussed in Appendix E (Quantitative Analysis).

Types of Energy Storage

Energy storage encompasses a broad range of technologies at very different levels of maturity. As discussed in Appendix H (Screening of Generation Alternatives), the Companies identified a long list of storage technologies for exploration in the Carbon Plan, but only four storage technologies made it through the technical and economic screening: advanced-compressed air energy storage ("A-CAES"), flow batteries, lithium-ion batteries and pumped storage hydro. These four technologies are the focus of this Appendix, as these are the technologies that are used to frame the characteristics of the selectable energy storage in the Carbon Plan modeling, as discussed in Appendix E (Quantitative Analysis). The Companies will monitor developments, pilots and demonstrations of non-selected storage options and may expand the list of technologies to include in biennial Carbon Plan updates.

Advanced – Compressed Air Energy Storage

A-CAES offers longer duration storage than typically found in batteries. A-CAES facilities use off-peak electricity to power a compressor train that compresses air into an underground reservoir. Energy is then recaptured by releasing the compressed air, heating it, and generating power as the heated air travels through an expander. Traditional CAES is a proven, utility-scale energy storage technology that has operated globally for over 30 years. However, to utilize traditional CAES, the project needs a suitable subterranean storage, which has typically been salt caverns, making the technology location constrained. A-CAES utilizes an engineered, mined hard rock cavern with hydrostatic compensation to increase energy storage density and reduce the cavern volume required, making it a viable option in geographies that do not have salt formations. The presence of suitable hard rock formations allows for A-CAES to be a possible solution in the Carolinas. A-CAES is also more efficient than traditional CAES, as it is adiabatic in which the heat of compression during the charge cycle is stored as thermal energy and used during the discharge cycle to heat the air, eliminating the need for a fuel, which is part of the traditional diabetic CAES process.

Flow Batteries

Flow batteries are comprised of positive and negative electrode cell stacks separated by a selectively permeable ion exchange membrane in which the charge-inducing chemical reaction occurs, and liquid electrolyte storage tanks, which hold the stored energy until discharge is required. Various control and pumped-circulation systems complete the flow battery system in which the cells can be stacked in series to achieve the desired voltage difference.

The flow battery is charged as liquid electrolytes are pumped through the electrode cell stacks, which serve only as a catalyst and transport medium to the ion-inducing chemical reaction. The excess positive ions at the anode are allowed through the ion-selective membrane to maintain electroneutrality at the cathode, which experiences a buildup of negative ions. The charged electrolyte solution is circulated back to storage tanks until the process is allowed to repeat in reverse for discharge as necessary. In addition to external electrolyte storage, flow batteries differ from traditional batteries in that energy conversion occurs as a direct result of the reduction-oxidation reactions occurring in the electrolyte solution itself. The electrode is not a component of the electrochemical fuel and does not participate in the chemical reaction. Therefore, the electrodes are not subject to the same deterioration that depletes electrical performance of traditional batteries, resulting in high cycling life of the flow battery. Flow batteries are also scalable such that energy storage capacity is determined by the size of the electrolyte storage tanks, allowing the system to approach its theoretical energy density. Flow batteries are typically less capital intensive than some conventional batteries but require additional installation and operation costs associated with balance of plant equipment. Although flow batteries' capital costs project to be higher than lithium-ion batteries, flow batteries are expected to become most effective as the duration of the battery is increased due to energy capacity being dictated primarily by the size of the tanks.

Lithium-ion Batteries

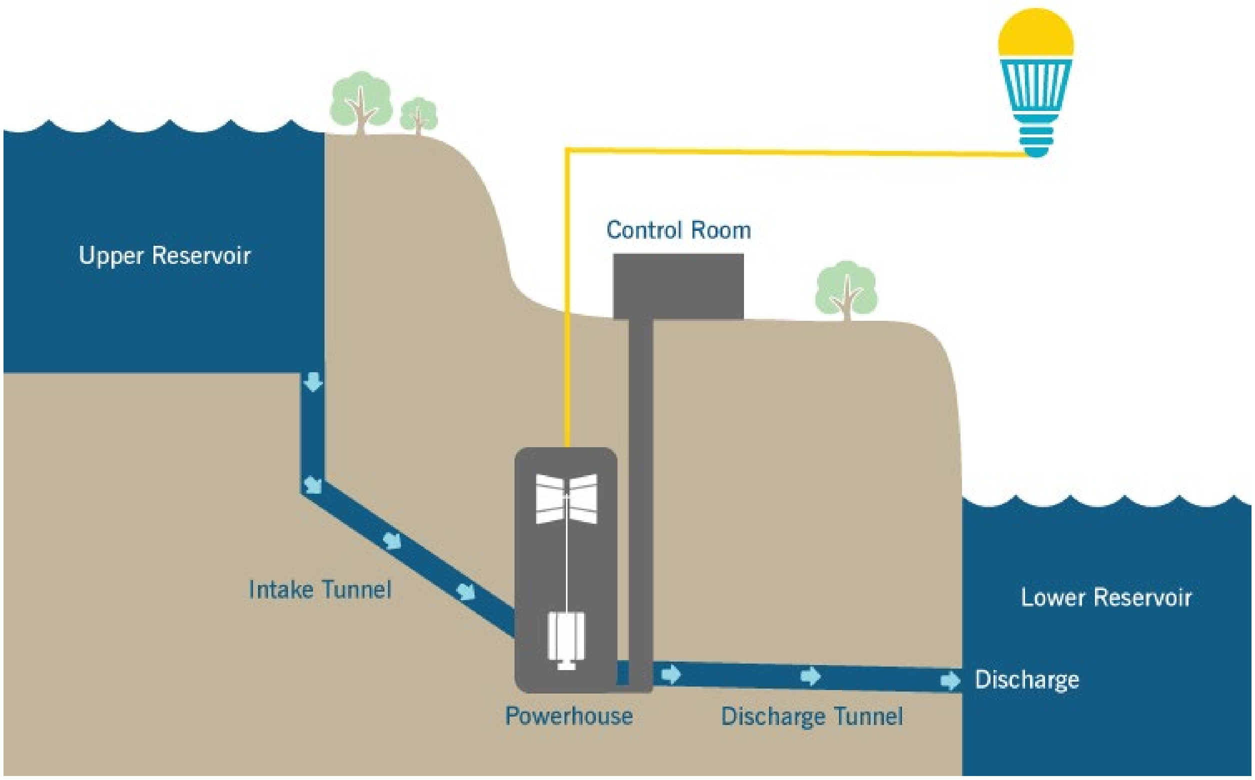
Lithium-ion (“Li-ion”) batteries contain graphite and metal-oxide electrodes and lithium-ions dissolved within an organic electrolyte. The movement of lithium-ions during cell charge and discharge generates current. Li-ion technology has seen a resurgence of development in recent years due to its high energy density, low self-discharge, and cycling tolerance. Many li-ion manufacturers currently offer 15-year warranties or performance guarantees. While recent supply chain disruptions have affected the li-ion cell market, longer-term cost declines and improved market conditions have allowed the technology to mature and for owners to gain operational knowledge. Consequently, li-ion has gained traction in several markets including the utility and automotive industries. Nearly all the energy storage capacity installed in the last decade was li-ion due to its cost advantage, technical capabilities (e.g., round-trip efficiency and fast response), range of applications and track record of the technology.

Pumped Storage Hydro

The Companies have operated PSH facilities for almost 50 years. The Companies operate two pumped storage hydro plants – Jocassee (1973) and Bad Creek (1991), as identified in Table K-1 above. These existing facilities provide most of the current energy storage within the Companies' system – 2,300 MW of storage capacity.

A flexible, dynamic and efficient way to store and deliver large quantities of electricity, PSH plants store and generate energy by moving water between two reservoirs at different elevations, as illustrated in Figure K-1 below. During times of low electricity demand, such as at night or on weekends, excess energy is used to pump water to an upper reservoir. The turbine acts as a pump, moving water back uphill. During periods of high electricity demand, the stored water is released through turbines. A pumped storage hydro system works much like a conventional hydroelectric station, except the same water can be used repeatedly.

Figure K-1: How Do Pumped-Storage Hydro Plants Work?



Future Developments and Federal Funding

Emerging energy storage technologies are coming to market with the goal of lowering marginal costs over traditional storage technologies. However, the early adopters of these technologies may not gain from this benefit of a lower-cost asset. This creates an important need for federal and private funding opportunities to help lower the installed costs of first adopter premiums to allow the advancement and eventual cost declines for these new technologies.

Investments in piloting and full-scale demonstrations of these emerging technologies will be essential in their development. However, due to technology scale-down limitations and a need for meaningful full-scale demonstration, much larger investments are required than traditional pilot testing. Duke Energy is actively evaluating funding opportunities to better understand the challenges and benefits that these emerging energy storage assets can offer at a competitive price to existing technologies.

Duke Energy is actively tracking funding opportunities and evaluating their relevancy to the Companies' decarbonization journey. The three Department of Energy initiatives highlighted below are examples of these opportunities. These programs can be a great opportunity for customers as they will allow a full-scale energy storage asset to be deployed, providing value to the grid and accelerating the learning curve for Duke Energy, all at a reduced cost through the grant programs.

- **Long-Duration Storage Shot:**[1] To reduce the cost of grid-scale energy storage by 90% for systems that deliver 10+ hours of duration within the decade.
- **Long-Duration Energy Storage Demonstration Initiative and Joint Program:**[2] To establish a demonstration initiative composed of projects focused on the development of long-duration energy storage technologies.
- **Energy Storage Demonstration and Pilot Grant Program:**[3] To enter into agreements to carry out three energy storage system demonstration projects.

With long-duration storage assets playing an essential role in Duke Energy's net-zero strategy, it is important to begin the development of a full-scale demonstration system in the near term.

The Infrastructure Investment and Jobs Act ("IIJA") presents additional federal funding opportunities for early stage or more mature technology deployment. The North Carolina Utilities Commission has sought feedback about IIJA through Docket No. M-100, Sub 164. As mentioned in comments filed in that docket by DEC and DEP, the Companies have identified and are evaluating IIJA programs that could be used to fund various energy storage demonstrations or deployments.

Energy Storage in the Carbon Plan

Energy storage included in the Carbon Plan include both stand-alone storage and solar paired with storage ("SPS") across a range of durations. Table K-2 below summarizes the storage options the model was able to choose from to meet the targets of the Carbon Plan.

Table K-2: Energy Storage Options in the Carbon Plan Modeling

Stand-alone Storage	Solar paired with Storage
50 MW / 200 MWh	75 MW solar + 20 MW / 80 MWh battery
50 MW / 300 MWh	75 MW solar + 40 MW / 80 MWh battery
50 MW / 400 MWh	

In addition to the storage options included above, the Companies also modeled approximately 240 MW of 1- and 2-hour battery storage that represent inflight projects on the DEP and DEC systems.[4] This represents a limited amount of grid-connected battery storage projects that will allow for a more complete evaluation of potential benefits to the distribution, transmission and generation system, while also providing actual operation and maintenance cost impacts of batteries deployed at a significant

[1] Long Duration Storage Shot | Department of Energy. https://www.energy.gov/eere/long-duration-storage-shot.

[2] Long-Duration Energy Storage Demonstration Initiative and Joint Program | Department of Energy. https://www.energy.gov/long-duration-energy-storage-demonstration-initiative-and-joint-program.

[3] Energy Storage Demonstration and Pilot Grant Program | Department of Energy. https://www.energy.gov/bil/energy-storage-demonstration-and-pilot-grant-program.

[4] Total in development storage is 300 MW, inclusive of the 240 MW of 1- and 2-hour battery storage projects noted above and approximately 60 MW of longer-duration storage projects.

scale. This planned near-term battery storage deployment is also generally consistent with the Companies' 2020 Integrated Resource Plans ("IRP") Short-Term Action Plan. On the other end of the spectrum, the Companies also modeled a second powerhouse at Bad Creek Pumped Storage Hydro which is essentially a 12-hour storage facility in the Carbon Plan as further discussed in Appendix E (Quantitative Analysis).

During the Storage Operational/Cost Assumptions and System Configurations Technical Subgroup Stakeholder Meeting, stakeholders provided feedback on the storage options the Companies planned to include in the Carbon Plan. These suggestions were to include (1) a 2-hour duration storage option, and (2) a larger capacity storage option that is paired with solar. For SPS in the Carbon Plan, the Companies originally intended to only model a 4-hour battery that was sized at 25% of the solar facility, but based on this feedback, the Companies included a 2-hour storage option that was paired with solar, sized at 50% of the solar capacity.

Additionally, stakeholders had questions about the detailed design assumptions assumed for battery storage in the Carbon Plan. The following details the assumptions in the model, but it is important to note that these assumptions are generic model assumptions. At the time these resources are actually added to the system, the actual design of the battery storage may vary from what was assumed in the model.

- **Depth of Discharge:** The cost of the battery storage assets in the Carbon Plan assumes that the asset is designed to include a 90% depth of discharge ("DoD") constraint. This means that if a battery is designed with 100 megawatt-hours ("MWh") of usable energy, the total energy of the battery would be 111.1 MWh. The depth of discharge constraint is included to reflect requirements of the original equipment manufacturer to maintain the warranty on most batteries.

- **Degradation Management:** There are many alternatives for managing degradation of a battery asset over its lifetime. For purposes of Carbon Plan modeling, the Companies assumed that the battery storage system would be augmented on a regular basis to maintain a constant level of usable energy over the life of the battery asset. The cost of this augmentation is reflected in the fixed operating and maintenance cost included in the Carbon Plan model. The optimal degradation management strategy may vary on a case-by-case basis, and the assumption used in the development of the Carbon Plan may change over time as the Companies continue to evaluate the benefits and costs of these strategies.

- **Round-Trip Efficiency:** The Companies assumed an 85% round trip efficiency for battery storage in Carbon Plan modeling. Duke Energy uses A/C – A/C efficiency as the production cost models only consider the charging/discharging at the point of interconnect to the power system.

While there are various types of storage technologies, in the near term, the Companies plan to deploy megawatt-scale electrochemical batteries and continue to partner with diverse suppliers who can provide the latest battery technology expertise and resources. Duke Energy will simultaneously continue evaluation of new long-duration storage technologies, including their cost, timing of commercial viability, and value to the grid. The Companies are in an optimal position to ensure compliance with rapidly evolving regulations and standards related to safety, reliability, and cybersecurity of energy storage systems.

Energy storage will play a critical role in the low-carbon future of the power system. Energy storage does not create carbon emissions when charging or discharging and can be charged off zero-carbon resources including nuclear power, solar, wind and hydro. Energy storage also provides the system benefit of allowing excess zero-carbon power to be stored for later use instead of curtailed. The dispatchable nature of energy storage allows this energy to be injected back onto the grid when it is needed most, offsetting higher cost carbon-intensive generation.

Execution and Risk Management

Delivering on the HB 951 70% interim target will require development of approximately 2,500 MW to 3,700 MW of storage, inclusive of 4-hr and 6-hr grid tied battery energy storage, battery energy storage at solar-plus storage sites, and pumped storage hydro, as discussed further in Chapter 3 (Portfolios).

As the grid becomes more reliant on energy storage to serve customers, several enablers, including technology, policy, and economic development, will be required to ensure that a market of commercially viable energy storage solutions develops. Duke Energy customers will benefit from a diversified storage portfolio and a diversified supply chain. For example, raw materials and associated components for lithium-based batteries and pumped storage hydro are very different. As such, the inclusion of multiple types of energy storage technologies in the Carbon Plan not only provides diversification in the physical operational characteristics of the storage technologies but also provides diversified supply chain and manufacturing risk exposure for customers. In addition, there are critical risks to the development of energy storage technology solutions as a whole and specifically the Companies' ability to develop as much as is specified in the Carbon Plan.

Timing and interconnection: Like many of the other generation resources that need to be developed to execute on the Plan, interconnection is a primary risk for energy storage projects. The volume of new energy storage that can effectively be interconnected each year is uncertain, given the inherent limitations on the amount of new resources that can be interconnected on an annual basis and the competition over interconnection projects with other resources that must be developed to execute on the targets of HB 951.

Supply chain and price certainty: Current socio-political, economic, and COVID-19-related events have created challenging market conditions for the entire industry to obtain long lead time electrical components. There are several impacts that the supply chain can have on the overall cost and availability of energy storage technologies, such raw materials, freight, and competition with other industries dependent on batteries such as cellular communications and electric transportation. Duke Energy will continue to gather information on the potential impacts of supply chain constraints and proactively engage in these industry issues.

Labor shortages: Many of the energy storage technologies that will be deployed as part of the Plan are relatively new technologies. As such, the talent pool for subject matter experts is relatively small. Duke Energy expects that the workforce educated to support design, installation, and management of energy storage resources will increase over time, but the high demand for energy storage resources required by the speed of this Plan could strain resource availability.

Communications/Control (site, DCC, ECC, RROC, etc.): Currently there is not an efficient mechanism for scheduling and dispatching battery groupings. Each operating entity currently manages assets across the transmission and distribution systems independently. Efforts are underway to develop tools and processes that aid in seamless implementation of charge and discharge schedules.

Forecasting and resource modeling techniques: Modeling and planning tools must constantly evolve to enable the distributed energy grid of the future.

Conclusion

Energy storage will play a key role in Duke Energy's pathway to meeting the CO_2 emissions reductions targets outlined in HB 951. As an increasing number of intermittent renewables are deployed, this technology will ensure that firm capacity needs are met, bolstering reliability and decarbonization efforts. Duke Energy will continue to monitor opportunities for federal funding to evaluate the commercial viability of these breakthrough technologies within the next decade. While there are multiple risks associated with new energy storage technologies that need to be monitored, the Companies will stay abreast on industry developments to best utilize the technology in bringing value to customers in the Carolinas.